Decoding the Amplitude-Modulated Part the DCF77 Longwave Time Signal by using the Goertzel Algorithm

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***Abstract*—The DCF77, a long wave time signal transmitter that is located near Frankfurt am Main in Germany, is the primary source of time information for radio-controlled clocks in Europe. Its signal consists of a phase and an amplitude-modulated part, both containing the time information. Devices that use the signal usually consist of an amplitude modulation long wave receiver, often realized by using a dedicated integrated circuit, and an application processor. In this paper, an alternative approach for the demodulation of the amplitude-modulated part of the signal, without the need for specialized analog cicruitry and only a minimal amount of simple hardware components, is presented. This is done by utilizing direct-sampling software-defined radio techniques together with leveraging the efficiency of the Goertzel algorithm. As a result, the presented approach removes the need for most of the usually employed analog circuitry, leaving only a front-end amplifier, and therefore effectively proposes a new type of design where the receiver is implemented inside the application processor. The employed lightweight algorithms keep it realizable on a system with limited resources, which is shown in an example implementation on a Arm Cortex-M3 microcontroller.**

***Index Terms*—DCF77, Goertzel, Digital Signal Processing, Time Signal, Software Defined Radio**

I. Introduction

Radio controlled clocks are very popular because they dont require periodical re-adjustment in comparison to common mechanical or quartz-powered clocks. Instead, the information about the current time is obtained from a RF-signal that is transmitted by an official authority that ensures its availability and correctness. The probably most important time signal in Europe is transmitted by the station DCF77 from Mainflingen, a city in Germany that is close to Frankfurt am Main. The station is operated by a private company that is commissioned by the Physikalisch-Technische Bundesanstalt (PTB) which also supplies the current time information, generated by two caesium clocks and two caesium fountains. Its operating frequency lies in the long wave area at $77.5\,\mathrm{kHz}$ and the time signal uses simple modulation techniques (amplitude and phase-modulation) and transmits with $100\,\mathrm{kW}$ Effective Isotropic Radiated Power (EIRP) to enable the reception of the signal in relatively close distances (up to $2000\,\mathrm{km}$) with simple technical equipment [2].

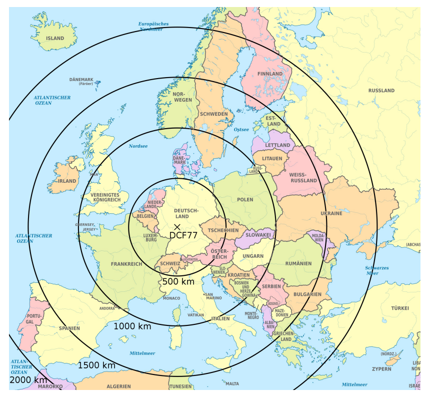


Fig. 1. Coverage of the DCF77 signal. Adapted from [1]

End-user devices usually make use of the amplitude-modulated part of the signal by using an amplitude modulation receiver, often a by employing specialized integrated circuit, together with a rather big ferrite-rod antenna to obtain the time signal. This time signal then needs further hardware, often in form of a microcontroller used as the applicaton processor, to decode and retrieve the actual time information. With the increasing availability of computation power and Digital Signal Processing (DSP) capabilities inside cheap mixed-signal microcontrollers, which are already used to process the time information, the idea to replace to replace the analog receiver portion with a Software Defined Radio (SDR) is more or less obvious. Moving the receiver into the application processor would allow for a simpler hardware design by shrinking down the complexity and the parts count of the external analog circuitry. In fact, only a tuned antenna with a basic pre-amplifier is needed.

In this paper, a straightfoward principle for designing a lightweight receiver for the DCF77, based on SDR-techniques, is presented. After taking a look at the structure of the DCF77 signal, the theoretical operation principle of the receiver is explained and shown in a MATLAB simulation. To further underline the simplicity and the possibility to implement the principle on a system with limited resources, a demonstration on a Arm Cortex-M3 microcontroller is shown.

II. The DCF77 signal

The DCF77 station operates in the long wave area at a frequency of $77.5\,\mathrm{kHz}$. Its operation started with transmitting a frequency standard in 1959. In 1973, the transmission of the current time information was added to the signal by using amplitude modulation. To allow a reception under more challenging conditions and with a higher resolution and accuracy, the same time information is also added to the signal since 1983 by using phase-modulation [3]. The two different parts of the signal that result out of the parallel amplitude and the phase-modulation can be used for different use-cases that are separated by the requirements regarding the resolution, accuracy, and the reliability of the obtained time information. Whereas the amplitude-modulated part is mainly used for general-purpose time application with low resolution requirements, the phase-modulated part is usually used for specialized applications that require a higher resolution, accuracy, and reliability. Although being considered as low in comparison to what is achievable by analyzing the phase-modulated part, the usually observed accuracy uncertainity when using the amplitude-modulated part it is still well below $1\,\mathrm{s}$, being $100\,\mathrm{ms}$ [2]. When using the phase-modulated part, a standard deviation of $\pm 2\,\mu\mathrm{s}$ to $\pm 22\,\mu\mathrm{s}$ from the atomic clock to the receving device can be observed [4].

As the amplitude-modulated part allows simplistic receiver designs through its straightfoward modulation scheme, it is used in the principle presented in this paper and therefore a focus is put on explaining this part of the DCF77 signal. The following explainations in this paper therefore refer explicitly to the amplitude-modulated part. The time information, represented as a series of binary symbols, is modulated onto the carrier with a frequency of $77.5\,\mathrm{kHz}$ by using Amplitude-Shift Keying (ASK). Every symbol has the duration of exactly $1\,\mathrm{s}$, with a part that is either $100\,\mathrm{ms}$ or $200\,\mathrm{ms}$ long where it has a value to zero. This the duration of this "gap" is used to encode respectively a 0 or a 1 and effectively switches the strength of the carrier between $15\,\%$ and $100\,\%$ [5].

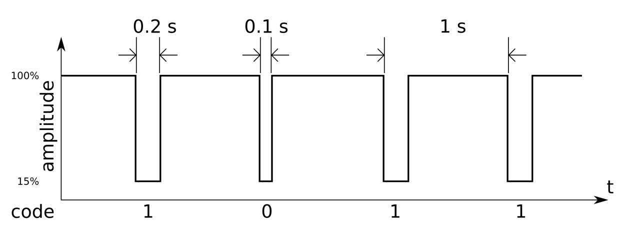


Fig. 2. Symbol encoding of the DCF77 signal. From [1]

To allow the detection of a new minute, the gap is left out between the last (59) second of the ongoing and the first (0) second of the next minute. By using this scheme, a dataframe consisting out $59\,\mathrm{Bit}$, starting at second one, can be transmitted every minute. Bit 0 to 19 are used to send encrypted weather data, to notify the PTB in case of errors in the transmitter, to announce an upcoming switch to or from Daylight Saving Time (DST), to show if DST is currently enabled or not, and to announce an upcoming leap second [5]. As the decryption of the weather date requires a specialized third-party integrated circuit and the notification bit is only important for the PTB, these parts of the frame are discarded by most applications. The leftover Bits 20 to 58 are used to represent the current time and date in Binary Coded Decimal (BCD) format, including parity bits for recognizing errors.

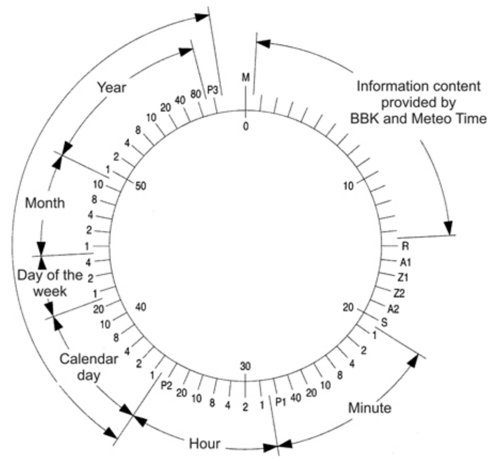


Fig. 3. Data frame encoding of the DCF77 signal. From [5]

This means that a receiver needs to run at least for $39\,\mathrm{s}$ after powerup to receive one whole block containing the current time information. In reality, this period is usually longer because the receiver needs to adapt to the current receiving conditions. These conditions underly a lot of influences, including temporary fading, electromagnetic noise from the close environment or varying signal strengths during different times of the day.

III. Principle of the receiver

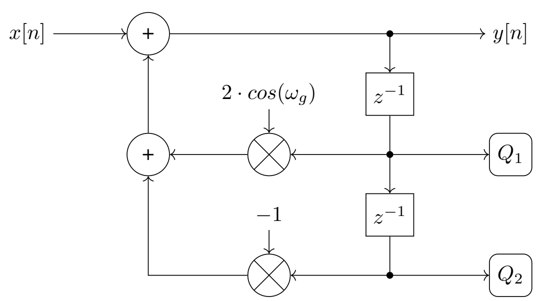
As the seen in the description of the DCF77 signal, retrieving the the binary time signal from the amplitude-modulated part is more or less trivial. Conventional applications execute this task by using analog receiving circuits, usually by using a simple amplitude modulation receiver together with a tuned ferrite-rod antenna, acting as a Bandpass Filter (BPF), to filter out the irrelevant part of the spectrum. Moving the receiver into the digital domain allows for more advanced techniques to retrieve this binary time signal, rather than demodulating the signal with a diode-detector inside the amplitude modulation receiver. Because the information is contained only in the amplitude of the signal, and therefore inside the signal strength at the receiver, it can also be obtained by doing a continuous analysis of the spectrum at the carrier's frequency of $77.5\,\mathrm{kHz}$.

A. The Goertzel Algorithm

The standard approach to analyze a spectrum in the digital domain after sampling is the well-known Discrete Fourier Transform (DFT), implemented by using the Fast Fourier Transform (FFT). This yields an analysis of the complete spectrum, producing $\frac{N}{2}+1$ relevant results for equally distributed frequencies (”frequency bins”) within range from $0\,\mathrm{Hz}$ to $\frac{f_s}{2}$ where N is the number of samples and f_s the sampling frequency [6]. The signal strength, and therefore the binary time signal of the amplitude-modulated part can then be examined by observing the value of the curresponding frequency bin over time. Because of only one frequency bin being relevant, it is obvious that a full FFT produces a lot of overhead and redundant calculation operations in this use-case. This overhead can be avoided by using the Goertzel algorithm instead of the FFT, which is able to calculate the value of one specific frequency bin with a smaller amount of needed calculations. It was invented in 1958 by Gerald Goertzel and since then most commonly used in the detection tones employed in Dual-tone Multi-frequency (DTMF) signaling [7]. The working principle of the algorithm can be percieved as a second-order Infinite Impulse Response (IIR) filter where the results $y[n-1]$ and $y[n-2]$ of the output are stored in states Q_1 and Q_2, so they are still available after the execution of the filter.

$$y[n] = x[n] + 2 \cdot cos(\omega_g) \cdot y[n-1] - y[n-2] \tag{1}$$

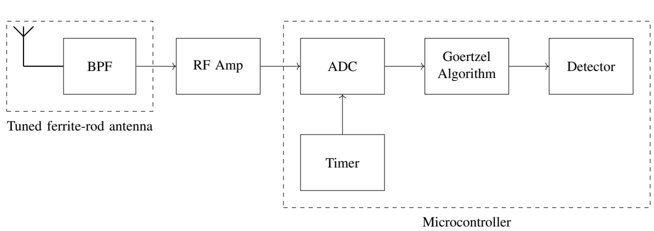
From these equations, the following structure can be derived:



The constant $2 \cdot cos(\omega_g)$ is computed before the execution. It is calculated based on ω_g and defines the frequency to be analyzed, dependent on the sampling frequency f_s, the frequency to analyze f_a and the number of input samples N.

$$k = \left\lfloor \frac{N \cdot f_a}{f_s} \right\rceil \tag{2}$$

$$w_g = \frac{2\pi \cdot k}{N} \tag{3}$$



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Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, ac, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

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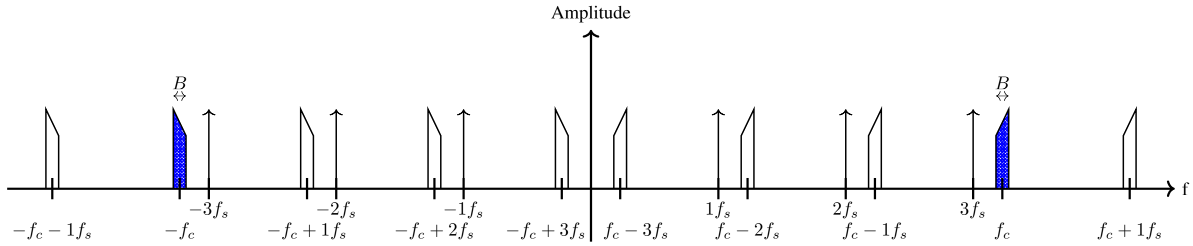
$$a + b = \gamma \tag{4}$$



Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(4)", not "Eq. (4)" or "equation (4)", except at the beginning of a sentence: "Equation (4) is . . ."

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- The word "data" is plural, not singular.
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TABLE I
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
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[a]Sample of a Table footnote.

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ACKNOWLEDGMENT

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REFERENCES

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Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

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For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

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